U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
A. C. TRUE, Director.

IRRIGATION AND DRAINAGE INVESTIGATIONS

OF THE

OFFICE OF EXPERIMENT STATIONS,

U. S. DEPARTMENT OF AGRICULTURE.

BY

R. P. TEELE,
Editorial Assistant, Office of Experiment Stations.

WASHINGTON:
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OFFICE OF EXPERIMENT STATIONS

A. C. True, Ph. D., *Director.*
E. W. Allen, Ph. D., *Assistant Director.*

IRRIGATION INVESTIGATIONS.

Elwood Mead, *Chief.*
R. P. Teele, *Editorial Assistant.*
C. E. Tait, *Assistant, in Charge of Central District.*
Samuel Fortier, *Irrigation Engineer, in Charge of Pacific District.*
C. G. Elliott, *Engineer, in Charge of Drainage Investigations.*

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., July 5, 1904.

SIR: I have the honor to transmit herewith and recommend for publication a brief account of the irrigation and drainage investigations of the Office of Experiment Stations. This account is intended primarily for distribution at the Louisiana Purchase Exposition in connection with the exhibits of this Office in the Government building and of the agricultural colleges and experiment stations in the Palace of Education.

Respectfully,

A. C. TRUE,
Director.

Hon. JAMES WILSON,
Secretary of Agriculture.

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By R. P. TEELE, *Editorial Assistant.*

HISTORICAL.

The irrigation investigations of the Office of Experiment Stations were first provided for in the agricultural appropriation act of 1898, which contained an item of $10,000 "for the purpose of collecting from agricultural colleges, agricultural experiment stations, and other sources * * * valuable information and data on the subject of irrigation, and publishing the same in bulletin form." The general supervision of this work was assigned to the Office of Experiment Stations. In order to determine the lines of information most valuable to the regions where irrigation is necessary, a conference of experiment station officers and irrigation engineers who had been prominently connected with western irrigation development was held in Denver, Colo., July 12 and 13, 1897, and was attended by officers of the experiment stations of California, Colorado, Montana, Nebraska, Utah, and Wyoming, and by the State engineers of Colorado, Nebraska, and Wyoming, besides representatives of the United States Department of Agriculture. At this conference it was decided that the best results could be obtained by carrying out this work along two general lines: (1) The collection and publication of information regarding the laws and institutions of the irrigated region in their relation to agriculture, and (2) the publication of available information regarding the use of irrigation waters in agriculture as shown by the actual experience of farmers and by experimental investigations, and the encouragement of further investigations in this line by the experiment stations. The work was organized according to these suggestions, and was, therefore, divided into two classes, the legal and economic, and the cultural. Following the conference, the work was placed under the direct charge of Elwood Mead, at that time State engineer of Wyoming. This action was indorsed by Congress at its next session, when it provided for the investigation of (1) "the laws and institutions relating to irrigation" and (2) "the use of irrigation waters, with especial suggestions

for better methods for the utilization of irrigation waters in agriculture than those in common use." The appropriation for the work was increased to $35,000.

The original law provided for the collection of information from the agricultural colleges and experiment stations and the law for the succeeding year authorized the stations to coöperate with the Department in the investigation of the subjects specified. In accordance with the law, the work has been very largely done in cooperation, to the great advantage of both the stations and the Department. A small amount of financial assistance from the Department has enabled the stations to extend their experiments in irrigation, while the money thus spent brought to the Department larger returns than could be secured in any other way, since it secured the use of the lands and equipments of the stations free of cost and the services of their investigators by paying only small parts of their salaries. Thus the Department secured for a few hundred dollars the making of experiments which would have cost as many thousands of dollars if carried on independently of the stations.

For the years ending June 30, 1901, and June 30, 1902, the appropriation was increased to $50,000, but the work authorized was not changed. For the year ending June 30, 1903, the appropriation was increased to $65,000, and the work was considerably enlarged. The added work provided for included studies of (1) the laws affecting the rights of riparian proprietors; (2) the use of irrigation waters abroad as well as at home; (3) plans for the removal of seepage and surplus waters by drainage; and (4) the use of different kinds of power for irrigation and other agricultural purposes. In the act making appropriations for the Department of Agriculture for 1905 the growing importance of drainage studies was recognized by a change of the title of the investigations to "Irrigation and drainage investigations," and an increase in the appropriation, the section providing for this reading as follows:

Irrigation and Drainage Investigations: To enable the Secretary of Agriculture to investigate and report upon the laws of the States and Territories as affecting irrigation and the rights of appropriators and of riparian proprietors and institutions relating to irrigation and upon the use of irrigation waters, at home and abroad; with especial suggestions of the best methods for the utilization of irrigation waters in agriculture, and upon plans for the removal of seepage and surplus waters by drainage, and upon the use of different kinds of power and appliances for irrigation and drainage, and for the preparation, printing, and illustration of reports and bulletins on irrigation and drainage, including employment of labor in the city of Washington or elsewhere; and the agricultural experiment stations are hereby authorized and directed to cooperate with the Secretary of Agriculture in carrying out said investigations in such manner and to such extent as may be warranted by a due regard to the varying conditions and needs and laws of the respective States and Territories as may be mutually agreed upon, and all necessary expenses, sixty-seven thousand five hundred dollars.

NEED OF IRRIGATION AND DRAINAGE IN THE UNITED STATES.

The rainfall over one-third of the United States is so scanty that irrigation is a necessity to the profitable growth of agricultural crops. In other sections of the country there is an area equal in size to all New England, with Indiana added, which is so wet that crops can not be grown at all, and where settlement and cultivation must be postponed until the land has been diked and drained.

In the fifteen States and Territories of the arid region irrigation is the fundamental agricultural problem, because the very existence of civilized life depends in large measure on the ability to use rivers for this purpose. In these States the production of a cheap and abundant home food supply, made possible by irrigation, has increased the comfort and lessened the cost of living, and contributed in a greater degree than any other single cause to their continued growth and prosperity. By it desert wastes have been transformed into the most productive, healthful, and beautiful habitations of man to be found on this continent. The cities of Denver, Salt Lake, Los Angeles, and many others of lesser note are as much the creation of irrigation as the orchards and farms which surround them, and all depend for existence upon water and the institutions which govern its ownership and use.

In many humid sections of the country high-priced land and intensive methods of cultivation are making of irrigation a factor of continually increasing value and importance, and it would seem that the experience of the United States, like that of Europe, will prove that no agent of agriculture or horticulture is so effective in increasing and insuring large yields as the ability to apply water in the right amount and at the right time.

There are large areas of land which always receive too much water, large areas which never receive enough, and yet larger areas which have sometimes too much and sometimes too little water. Only by proper control of the water supply can these lands be made to produce the best crops, and such a control includes both irrigation and drainage, some lands needing one, some the other, and some needing both. The greater part of the land now farmed in the United States belongs to the last class. The experiments made by this Office and the experience of farmers and gardeners show that irrigation in dry years, even in the regions of heaviest average rainfall, much more than repays the cost of supplying the water. In these regions crops are as often drowned out as burned out, and it is probable that drainage to remove water in wet years will prove as profitable as irrigation in dry years.

The area of land in the United States east of the one hundredth meridian which is too wet for agricultural use but which can be reclaimed

by drainage has been estimated by Prof. N. S. Shaler at from 105,000 to 131,000 square miles,[a] or from 67,200,000 to 83,840,000 acres. It is a notable fact that this is practically the same as the estimates of the area which can be reclaimed by irrigation; that is, the area east of the one hundredth meridian which can be reclaimed by drainage equals that west of that line which can be reclaimed by irrigation. These wet lands have received for centuries the alluvial deposits from the streams which overflow them and the vegetable mold from the rank growth which covers them, so that when relieved of their surplus water they are among our most productive lands, competent authority estimating their productive capacity as being four times that of the State of Illinois.

The irrigation and drainage investigations of the Office of Experiment Stations were established by Congress to study the best methods of utilizing these two aids to agriculture, to determine the best methods of securing, distributing, and applying water to land when it is too dry, and of removing water from land when it is too wet. The following pages will give a brief outline of the work which is being carried on, and of some of the results which have been secured.

THE IRRIGATION INVESTIGATIONS.

While accurate statistics are lacking, it is certain that more than $200,000,000 has been expended in the United States in the construction of canals and reservoirs for distributing water in irrigation and in preparing land for its application. More than 10,000,000 acres of land are being watered each year and more than 15,000,000 acres are capable of being watered from the canals and ditches already built. The greater part of this water comes from creeks and rivers, hundreds of these being completely emptied at some season each year in order to meet the needs of the fields along their banks. Other ditches are supplied from reservoirs, of which thousands have already been built. Still other ditches are filled from water lifted from wells. In all, the welfare and prosperity of several million homes and the future industrial importance of more than one-third of this country is dependent upon the successful working of the laws and practices for the control and utilization of water which have grown up in the western part of the United States within the past fifty years. The rapidity and extent of this irrigation development has had no counterpart in any other country. It has been carried out by men to whom all its problems were strange and new, and, in many cases, where scanty population, lack of transportation facilities, and limited means on the part of settlers have added to both the difficulty and the cost of the work. The results already secured furnish a remarkable illustration of the

[a] Fresh Water Morasses of the United States.

energy and capacity of the American farmer, but the time has come when this kind of development should be replaced by one less wasteful and more orderly. Of necessity much of the early work was done in an unsatisfactory fashion, many of the methods of using water are crude and imperfect, and the social and legal organizations under which rivers are now being fought over are not adapted to securing the largest and best results or to meeting the requirements of the time when increasing value of water and greater demand for its use by an increased population will intensify the struggle over its possession. Many of the problems created by this development have already assumed a complexity and importance which makes it plain that their solution can only be effected through painstaking investigation, which will embrace widely scattered areas and be directed and interpreted by men of experience and ability in irrigation engineering and irrigation practice. The investigations during the past five years have been directed toward building up an organization of experts, who shall be investigators rather than construction engineers and who shall study all problems from the standpoint of the farmer.

DUTY OF WATER.

The first question which confronts the farmer in the arid region is the amount of water required to insure crops on the land he is to cultivate. He needs this information in order to make an intelligent bargain for water where he rents it from a canal company, or to fix the size of the canal he builds himself. He needs to know when this water will be required—how much in May, how much in August—in order to determine whether the stream, reservoir, or well he depends on can supply it. The amount he must have varies widely in different localities and with different products. The irrigation of small grains, as a rule, ends with July; the irrigation of many root crops does not begin before this month, while the irrigation of alfalfa continues throughout the growing season.

He should also be able to estimate how much of the water taken in at the head gate will be lost by seepage in transit, because losses in transit in some instances amount to more than one-half of the total supply. For the past five years the Office of Experiment Stations, through its irrigation investigations, has been gathering and publishing this information for the benefit of farmers and ditch owners. Systematic measurements have been made in all parts of the arid region to determine the amount of water lost in transit in canals, the amount required by different crops, and the manner in which the quantity of water used can be influenced by greater care in the preparation of land, greater skill in the distribution of water, and by improvements to lessen seepage losses in diversion and carriage. Some of the results of these studies are given in charts exhibited at the

Louisiana Purchase Exposition, which show the average quantity of water required to irrigate an acre of land when measured at the head gate, the average when measured at the margin of fields, and the average requirements of different crops.

One of the results of these investigations has been to show that the loss of water from seepage is far more serious than had been generally supposed, even by canal owners and irrigation engineers, and that one of the most promising means of increasing the duty of water is to build better canals and devote more care to keeping them in first-class condition. It has already proven profitable in a few localities to line canals with some impervious coating in order to reduce or prevent seepage losses. Many miles of canals and ditches in southern California have been cemented at a profit (Pl. I), and the extension of this sort of work is only delayed because of uncertainty as to whether or not cementing is the cheapest and best means of securing a water-tight conduit.

One of the first difficulties encountered in the beginning of this work was the lack of an accurate, simple register to keep a continuous record of the water used. All those which were satisfactory were at that time imported from France. To-day they are practically all made in this country, a result which is chiefly due to the irrigation investigations of this Office. Designs of instruments were made by the experts, as experience showed what changes could be made to advantage. The drawings were given to the makers of such instruments. Some of the instruments which had their origin in the designs prepared by this Office, and which have been perfected in details by the various makers are shown in figures 1, 2, and 3.[a] They are now superior to anything used in the irrigated districts of Europe.

The accurate measurement of water is the first requisite in the efficient division of a river among those entitled to its water supply. In the preparation of weir tables, directions for placing weirs, and in discussion of the factors which influence water measurement, this Office has done much to direct and aid improvement along this line in every arid State.

Actual measurements of the quantity of water used in irrigation, and of the volume lost by seepage and evaporation in ditches, should have been made at the very outset in irrigation development in every important valley of the West. It is the only way in which a reliable guide can be had for framing water-right contracts between farmers and canal owners, and to enable courts to make a just and intelligent adjudication of rights to a stream. In order that an appropriation of water shall be limited to beneficial use we must first know how much is needed to supply that use.

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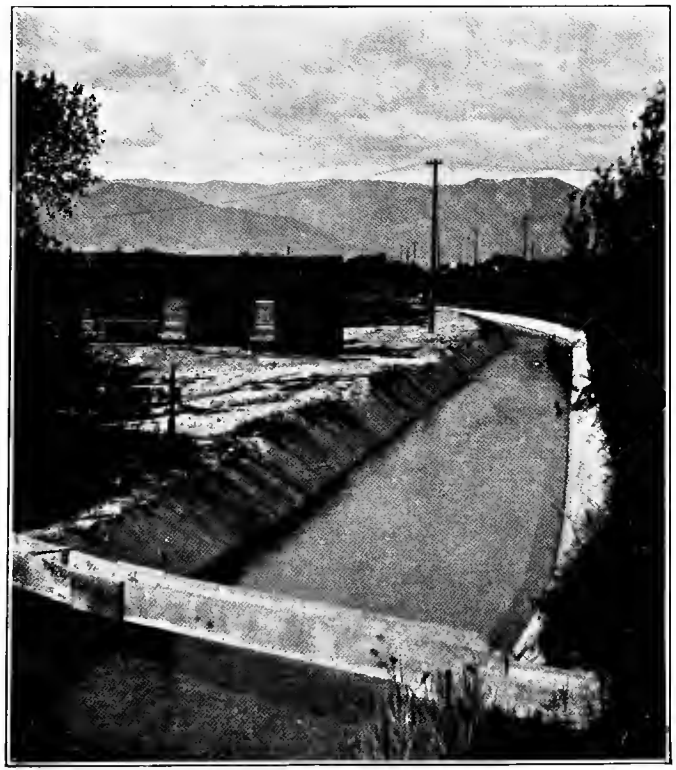
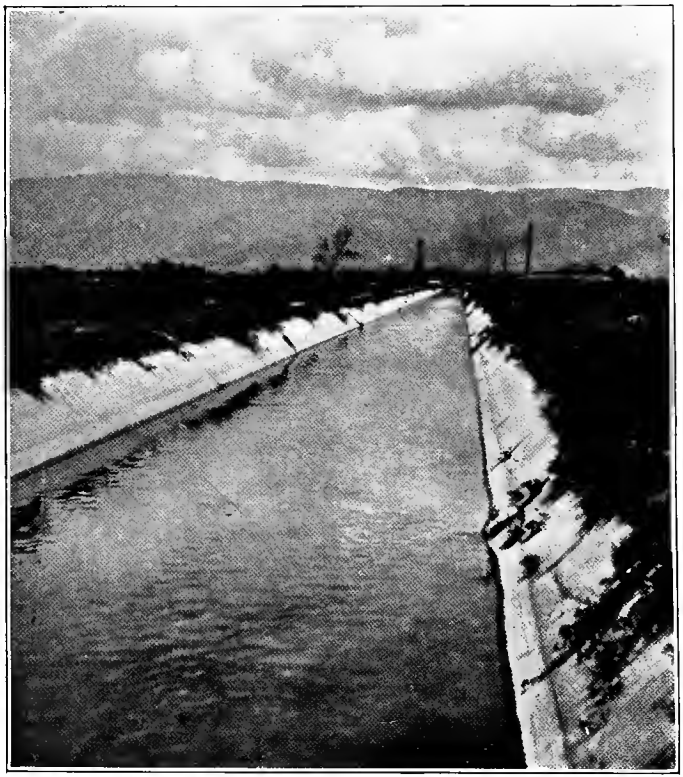
[a] These instruments are shown in the exhibit of the Office at the St. Louis Exposition.

PLATE I.





CEMENT-LINED CANAL, CALIFORNIA.

U. S. Dept. of Agr., Office of Expt. Stations, 723.

To show how little was known in the early settlement of these questions, it may be stated that along a stream 25 miles in length the amount of water bargained to be supplied under the early contracts varied from enough to cover the land to a depth of 1 foot in the season to enough to cover it to a depth of 7 feet during the same time, while the decrees of the court establishing rights to water varied from enough to cover the land to a depth of 1 foot in a season to enough to cover it to a depth of 400 feet in a season. The use made of the measurements carried on by this Office during the past five years by courts, legislators, ditch companies, and farmers has shown the need of these data. The averages obtained show that much more water is used than is needed, and lead to the belief that the water now used on one acre can, by better preparation of land and more skillful application, be made to serve two acres. General rules are not, however, sufficient for the working out of a satisfactory irrigation practice for the whole arid region, because soil, climate, and crop each influence the result and produce widely varying requirements in different sections. More than three times as much water is needed in Arizona as in Montana, because the summers are hotter and the growing seasons longer. What is needed, therefore, is investigations which will be sufficient in number and wide enough in geographical distribution to furnish an approximate guide for the practice of farmers in all sections of the country.

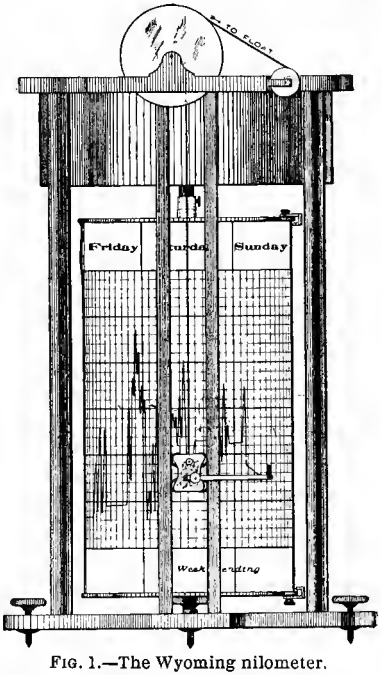


FIG. 1.—The Wyoming nilometer.

The earlier investigations dealt wholly with the quantity of water required under methods in common use. During the past two years a new series of original researches have been inaugurated, to determine what quantity of water will give the best results and what methods of application will secure the greatest economy in its use. A large number of experiments are being made in Utah, California, Oregon, and Montana, in which different quantities of water are being applied to the same crop by the same methods, in order to determine where the increased use of water ceases to be profitable, and also where it ceases to be beneficial. We wish to find out two things: What volume of water will give the largest yield for an acre of land, and what volume will give the largest return for each acre-foot of water used. Experi-

ments are also being made to determine what method of application will give the best results with the least loss of water from seepage and evaporation.[a] While the experiments were only begun last year, the results are most significant—nearly twice as much water being required

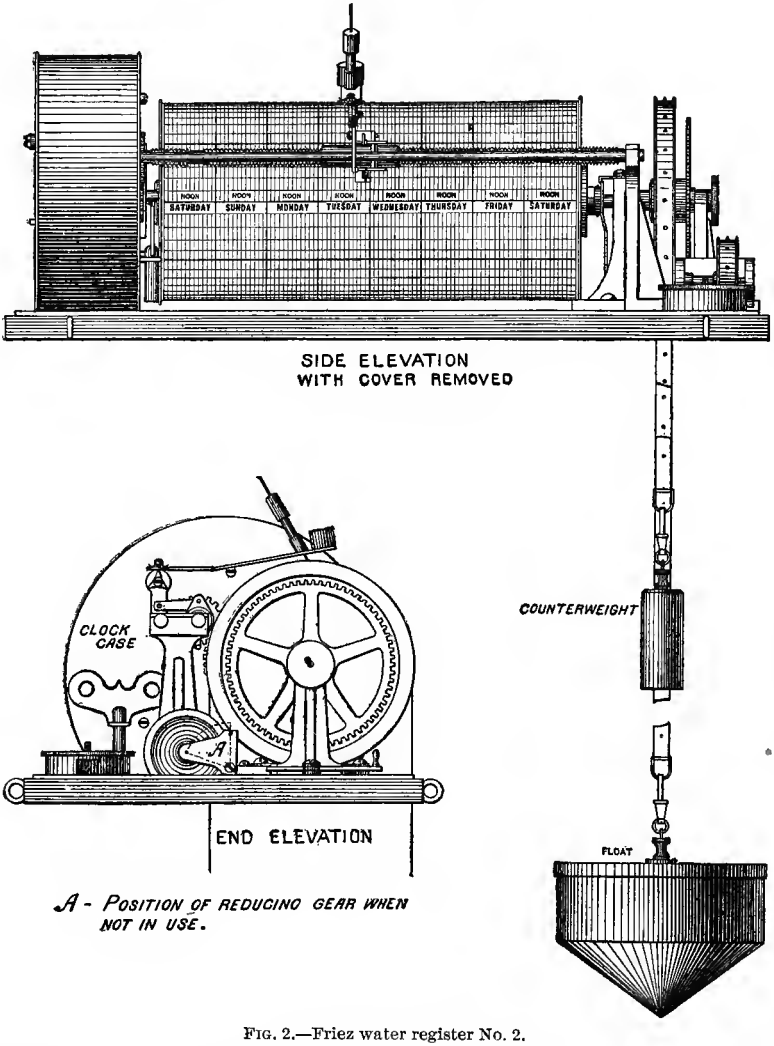


FIG. 2.—Friez water register No. 2.

to irrigate land by flooding as will serve where it is applied in deep furrows.

These investigations have also disclosed the fact that the character of water rights has an important influence on the volume of water

[a] Pictures of the tank experiments at Fresno, Cal., displayed in the exhibt at St. Louis, show how some of these studies are being carried on.

used in irrigation. Contracts which are based on the acres irrigated are a direct incentive to a wasteful use of water, because the farmer feels that the more water he uses on an acre the more he will get for the money paid. On the other hand, contracts which base the rental charge on the volume of water used encourage farmers to exhibit skill and economy in its application, because the less they put on their fields the smaller their water rentals will be. It makes it profitable to expend more money in the preparation of land, to put ditches in better condition, and to supplement irrigation by thorough cultivation.

After the water supply is secured, fields must be prepared for its application. The cost, the labor, and the skill required in putting an uneven surface in condition to have water reach, by gravity, every

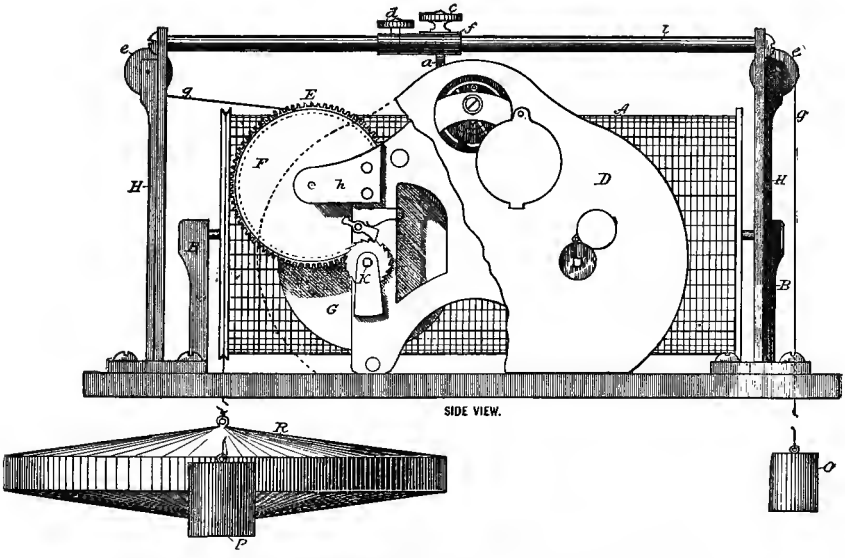


FIG. 3.—Water register manufactured for the Department (side view).

square foot of its surface have never been rightly appreciated. So much attention has been given to problems connected with the building of dams and canals that the work of the farmer, which, after all, determines what value the dams and canals are to have, has been neglected. No one who has made a study of our irrigation practice can fail to reach the conclusion that the outlay expended in preparing fields for the application of water, which includes removing brush, leveling uneven areas, and the building of laterals, is on the average equal to or greater than the cost of the main canals. Not only is this true, but, owing to lack of information regarding the methods of applying water, much of this money and labor has been lost. This waste and loss is going on continually, because each year tens of thousands of beginners in irrigation undertake the reclamation of new lands. If left to themselves they adopt the methods of their neighbors, without regard to

whether they are suited to their conditions. In too many instances they are not. There are in this country about thirty different systems of applying water to crops. To know which one of these is best suited to a particular farm requires a knowledge of the subject not possessed by the average irrigator or the average engineer. Nothing will do more to promote rapid and successful settlement of lands now arid than to show farmers how to save money and time in grading land and building laterals; but in order to advise regarding this, field investigations which will give an accurate idea of conditions are absolutely indispensable, and these are being made and reports prepared.

The results of studies of this kind made in one district show that to prepare the land for irrigation by the plan first adopted would involve an outlay of more than $3,000,000, or about twice the amount needed to build the canal. It has also been made apparent that fully half of this outlay can be saved by the adoption of a different method of applying water.

LEGAL AND ECONOMIC PROBLEMS.

When there is more water in the stream than all the irrigators need, farmers pay little attention to the nature of their rights to divert its flow; but as ditches increase in number until the stream does not carry enough water to supply all, the question of which head gate must be closed and which farmer must lose his crop because of this shortage becomes a matter of overshadowing importance. It is then that the irrigator with an imperfect right realizes that a valid title to water is more important than a title to land. The knowledge of his own lost labor, ruined crops, and his fields parched by drought is aggravated by the prosperity of his neighbors whose superior rights in the stream keep their ditches filled and their fields wet. In the absence of laws to govern the division of the water supply, or of agreements to regulate such division by mutual consent, the position of a canal on the stream determines whether it has an abundant or scanty water supply. The irrigator whose ditch is nearest the head of the stream, or whose lateral is nearest the head of the canal, uses or wastes water as he pleases. Those farthest down must take what is left, and when waste or use has exhausted the supply it is always the irrigator at the lower end of the stream or the farther end of the canal who is the first to suffer. To prevent the waste and injustice inevitable on such canals, there has been built up in each Western State a system of legal and social institutions intended to govern the relations of water users to each other and to determine and protect their rights to the water supply. As settlements have multiplied, demands on the streams have increased, and irrigators have come to realize that on the wisdom and justice of these institutions depend in large measure the value of irrigated land and the security, peacefulness, and profit which attend their work.

The Arkansas River in Colorado will serve to illustrate the importance of the social and legal problems of irrigation. One thousand nine hundred ditches divert this river in that State. Their aggregate length, exclusive of laterals, is more than 3,000 miles. About $9,000,000 has been expended in their construction. Six hundred thousand acres of land can be watered from them, and more than 400,000 is now being irrigated. Between 7,000 and 8,000 people depend on these ditches for their water supply, and they have invested large sums of money in the purchase of stock in the companies, in buying water-right contracts, or in the payment of annual water rentals. The value of the irrigable land thereunder is between $25,000,000 and $30,000,000. The cost of operating and maintaining these works is over $200,000 a year. Each one of these 8,000 irrigators knows that in order to grow a crop he must have his part of the water of the river at the time the crop needs it, and that if some other canal or some other irrigator takes his share his crops will be ruined, no matter how industrious or skillful he may be in their cultivation. With 8,000 irrigators scattered over a territory more than 200 miles in length and in places 50 miles wide, he also knows that he is dependent for his share of the water supply on the nature of the arrangements for preventing waste on the part of others and on the efficiency of the division of the stream between the 1,900 ditches which divert it. Unless the head gates of these ditches or canals are so adjusted that no one can take more than its proper share, and unless those not entitled to water are closed entirely when the protection of superior rights requires it, there must inevitably be injustice, bitterness of feeling, and failure of crops.

The final problem of irrigation becomes one of distribution and, to make this a success, the arrangements for transporting water to the laterals of the different farms should be carried out with the same order and system that marks the management of a railroad or express company. The difficulty of securing a satisfactory division of a river among irrigators is enormously increased by the fact that the volume of water to be divided is never uniform. It varies from day to day and from season to season. The flow of the Arkansas, for example, has been as high as 40,000 cubic feet per second and as low as 100 cubic feet per second. At its highest stage there was more water than all the canals could carry and the integrity of head gates was threatened. At its lowest stage there was not enough to wet the flumes. Irrigation on this stream has already been so extended that without storage of flood waters the crops on many fields must each year be parched by drought, and great storage reservoirs have been built and others are contemplated in order that the 200,000 acres of land under existing ditches, not yet irrigated, may be brought under cultivation. The water of many of these reservoirs has to be turned

into the river, mingled with that coming directly from the snows, and carried past the head gates of many ditches and canals not entitled to stored water, in order to reach the head gates of the canals under which its owners live. The difficulty of dividing the natural flow is therefore augmented by its union with the stored supply.

The great extent of territory embraced, the vast interests involved, the changing conditions regarding needs of irrigators, and the volume of water to supply them makes it manifestly impossible for each individual irrigator to protect and secure his own share. The farmer at the lower end of this valley can not cultivate his fields and watch the head gates of the canals above. As an individual he is helpless. The success of his own efforts and that of all other irrigators depends on public control and the enforcement of laws by men of broad experience and possessing tact, firmness, and administrative ability of high order. The greatest weakness of American irrigation to-day is the lack of effective administration of streams. [a]

Where the above facts have not been recognized continuous and expensive litigation over water rights has been the result, and this has been one of the heaviest burdens borne by the farmers of the arid States. It is made the more burdensome because it is wholly unproductive, the money spent in litigation being wasted, considering the industry as a whole. The amounts thus spent are a drain on the farmers now using water, and the probability of these controversies continuing is an effective check on further development. The prevalence of litigation is the most significant indication of inadequate or misfit laws, and a conclusive argument in favor of an investigation to show the direction which improvements should take. In carrying out the investigation of this subject certain typical districts have been selected and a careful study made of existing conditions, the object being first to obtain the facts, believing that they would be the most potent argument for reform. In presenting these facts investigators must be something more than reporters, and should present not only the existing situation but the causes by which it was created, and this has been done. The reports of this Office on the irrigation systems of California, Utah, Wyoming, Nevada, and Colorado have resulted in a great quickening of popular appreciation of the necessity for more effective laws.

Adequate legislation and efficient protection of rights is further hampered by the fact that State boundaries cut across the drainage lines of many irrigated valleys. The irrigated district of the Arkansas lies partly in Colorado and partly in Kansas. That of Bear River begins in Utah, extends into Wyoming and Idaho, and returns again

[a] This has been brought out in Bulletins 96, 100, 118, 124, and 140 of the Office of Experiment Stations.

to Utah. Differences in laws and customs and lack of efficient protection of rights in every one of these valleys means that priorities must be enforced along the entire stream, but this is not possible as long as a single authority is not in charge and as long as the nature of rights, customs, and prejudices differ as greatly as they do in different States at the present time. In order to determine what solution should be made of this problem, Congress has required the Office of Experiment Stations, through its irrigation investigations, to prepare a report on the laws affecting irrigation and the rights of riparian proprietors. This report will deal with a concrete illustration of the effect of existing laws, the Platte River being used. On this stream riparian rights are recognized at the lower end and only the rights of appropriation at the upper end. The report will deal with the laws, the number and character of existing rights, the methods of dividing water, and the flow of the stream as affected by diversions above and the return of seepage water below.

PUMPING FOR IRRIGATION.

The first lands irrigated were the bottoms along streams. Irrigation has gradually extended to the higher lands, with constantly increasing expense for canal construction. In many places the cost of a gravity supply has become so great that it is cheaper to pump water than to build long canals. In many other sections the only available water supply is from wells, the streams having so slight a fall that their diversion by gravity is impossible. Losses from canals and the irrigation of land are bringing the ground water nearer and nearer the surface until, in many instances, this ground water is the cheapest source of supply that farmers have. They can raise it to the surface by means of pumps with less expense than they can rent water from canals, and in addition they are free from the variations in supply or the complications over management so common to large canal systems. Recent discoveries of oil and improvements in transmission of electrical power have greatly reduced the expense of pumping water for irrigation.

This is a new branch of irrigation, and the ordinary farmer or water user under a gravity canal has had little opportunity of gaining information concerning it. During the past few years many pumping plants have been installed and much experimenting has been done at the expense of the owners, but the experience and knowledge thus gained by the few have not been made available to the many. A study of the cost and methods of pumping water forms an important feature of the investigations of this Office.

This branch of the subject is many sided. There are, for example, a comparison of the various fuels, the proper conditions for each kind and make of pumps and engines under which both will work at

their highest efficiency, the digging and boring of wells, the proper installation of plants, the effect of pumping on the ground-water supply, and the quantity required for the irrigation of different crops on soils of various characters. These and similar questions have been under investigation.[a]

IRRIGATION IN THE SEMIARID REGION.

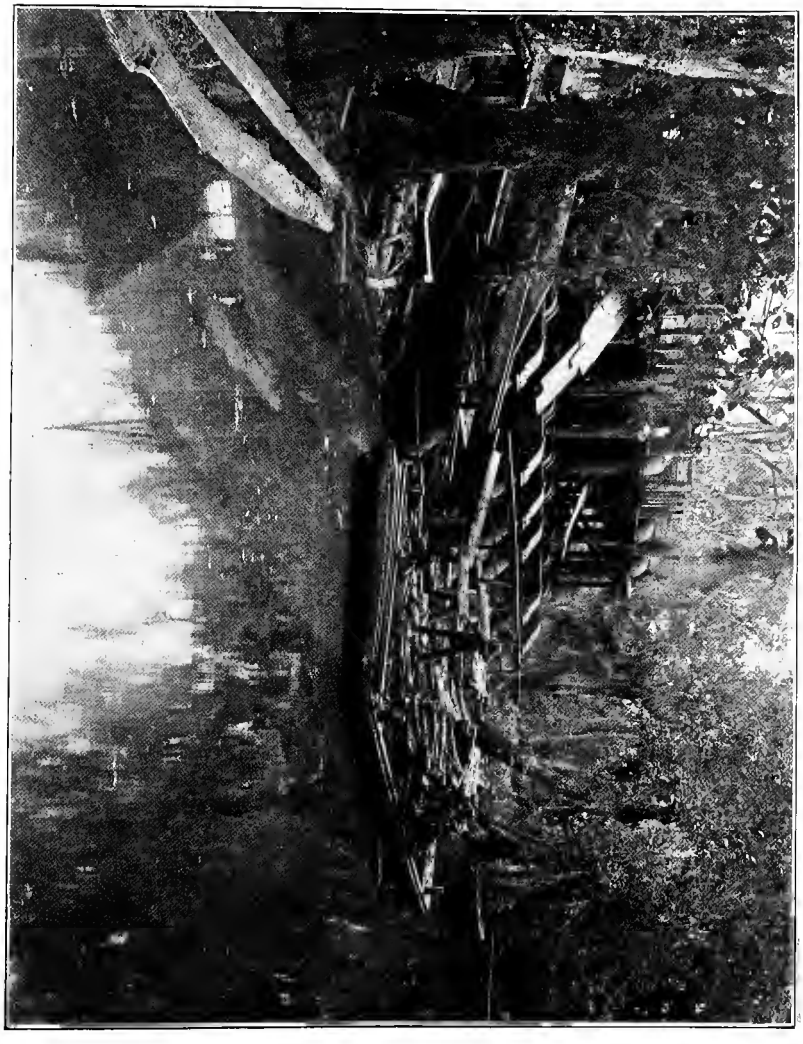
Between the eastern parts of Texas, Oklahoma, Kansas, Nebraska, and the Dakotas and the distinctively arid country which lies at the western border of these States there is a broad strip of country which extends from the northern boundary of the United States almost to the Gulf of Mexico. In this belt there is plenty of rain in many seasons to produce crops, but in others agriculture without irrigation is a failure. In all years the period in which irrigation is necessary is of brief duration only. In these sections farmers are confronted by two problems—how to make the limited water supply of that region available, and how to utilize it to the best advantage. Owing to the absence of large rivers and the intermittent character of the streams, the majority of farmers must depend upon two sources for their water supply—on what they can pump out of the subsoil of their farms, and what they can store in small reservoirs. In this region there have been recurring periods of wet and dry years, which have peopled and depopulated certain sections three or four times. Rainy years attract farmers and dry years drive them away. A special system of agriculture must be worked out for this part of the country, in which the total holdings of land will be comparatively large, but where each settler will be fortified by having from 10 to 20 acres of ground which he can irrigate, and which will assure him every year, whether it be a wet or a dry one, an ample supply of vegetables from his garden, some fruits, and enough alfalfa and forage to support his milch cows and other live stock.

Something of the possibilities of reclaiming land by means of pumps and small reservoirs is shown by the statistics of irrigation in India. In British India, within an area approximately equal to what is termed the semiarid region, 12,895,000 acres are irrigated with water which is raised by some mechanical means, while 8,138,000 acres are irrigated from "tanks," or reservoirs, most of which are supplied from storm water rather than from streams.[b]

It is believed that grain crops, at least, can be raised throughout the plains region by deep fall plowing, which will put the land in condition to absorb all the water which falls during the winter, and thorough

[a] The exhibit at St. Louis shows one of the typical pumps used in the western part of the irrigated district.

[b] Report of the Indian Irrigation Commission, 1901–1903, Pt. 1, p. 11.



PUMPING WATER FROM BAYOU FOR RICE IRRIGATION.

cultivation in the spring, which will prevent the evaporation of the soil moisture. Experiments are being made to determine the efficiency of this system of cultivation.

The use of pumps and windmills, the storage of storm waters in reservoirs and in the soil, will at least enable those engaged in the live-stock business on the plains to raise their own provisions and provide feed for their stock during winter storms. Much more is hoped for.

Experts having a knowledge of both the installation and operation of pumps, and of applying water to crops, are at work in western Kansas, Texas, and Arkansas, showing farmers the best methods of securing and applying water, and collecting data to show the possibilities and cost of providing a water supply throughout this vast region.

IRRIGATION IN THE HUMID REGION.

In the humid region irrigation is not necessary to profitable agriculture, as it is in the West, and the problem is not how to get the largest possible returns from a limited water supply, but whether the supplying of water to plants during dry seasons or during the short dry periods which occur in almost every season will increase production enough to repay the expense incurred. This, of course, includes a study of the most economical means of securing a water supply and the best methods of applying it to crops. Experiments made in Missouri, Wisconsin, and New Jersey have demonstrated that irrigation in those sections is highly profitable by the methods followed, and the experiments are being continued with a view to the determination of the best methods. The work in Missouri is mainly with small fruits and nursery stock. The experiments in Wisconsin include field as well as garden crops, and at present the irrigation of cranberries is being thoroughly tested. In New Jersey small fruits and garden crops have been irrigated.

The greatest field for irrigation in the humid district is, however, in the Southern States. Here comprehensive studies of the best methods of irrigating rice, the amount of water required, and the cost of supplying it where it must be raised from streams or wells by pumping (Pl. II), are being carried on. In addition, experiments have been instituted in connection with two of the experiment stations of the Southern States to determine whether or not ordinary field crops can be irrigated with profit. The great extension of irrigation in European countries, with a rainfall equal to or greater than our own and more evenly distributed, leads to the belief that it is to prove of equal advantage here. The diagram (fig. 4) shows the relation between the rainfall of the greatest irrigated district of Europe and that of typical humid sections of the eastern part of the United States.

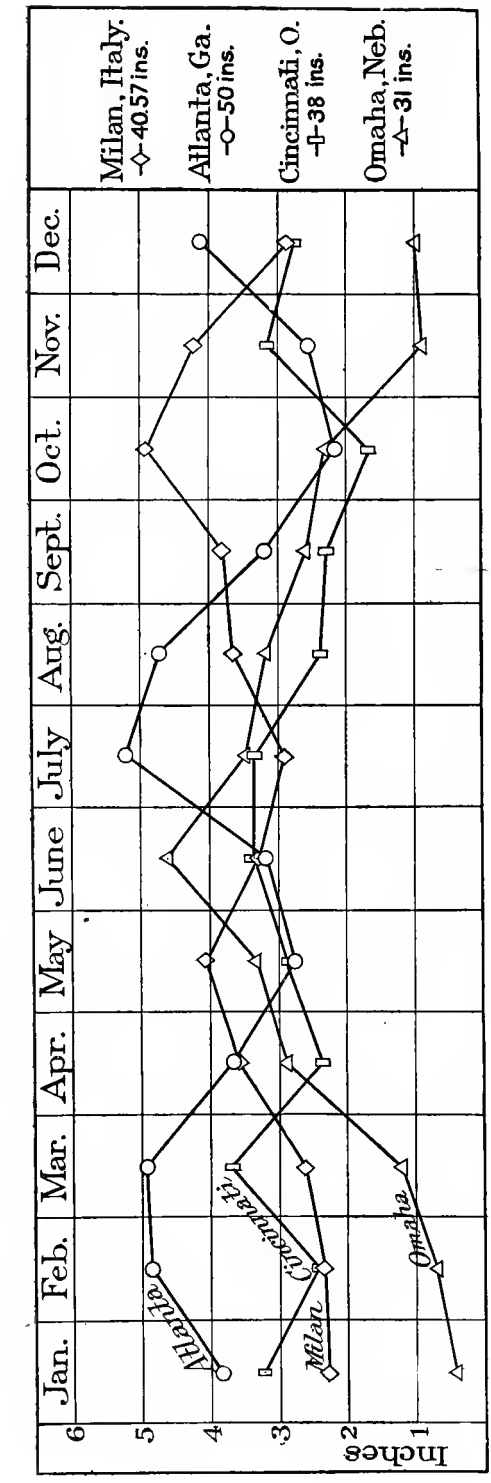


FIG. 4.—Diagram showing the relation between the rainfall of parts of Italy and that of humid sections of Eastern United States.

COMPOSITION OF THE WATER USED IN IRRIGATION.

A knowledge of the chemical composition of water used in irrigation is at times of great advantage. Some water supplies carry so large a percentage of alkaline salts as to make their continued use on land a serious menace. The silt borne by many streams is a fertilizer of great value and one of the most effective means of lessening seepage losses in canals and ditches. During the past four years, through the cooperation of the Bureau of Chemistry of this Department, the chemical department of the State Agricultural College of Texas, and the College of Agriculture in the University of California, numerous samples of water have been collected and the amount of silt carried in suspension and the alkaline salts in solution have been determined.

In the rice-growing district of Louisiana and Texas these analyses are needed to determine when the salt content, due to the inflowing sea water, becomes a menace to pumping machinery and the growing crop. In Texas many analyses have been made to determine the sediment value of the water used in irrigation and also to determine how the deposit of sediment is likely to impair the efficient operation of ditches or the life of reser-

voirs by filling them up. The work of Professor Nagle in Texas showed that the quantity of silt carried by southern streams is too important a factor to be ignored in the construction of either ditches or reservoirs.

During the present season a large number of water samples are being taken and analyzed in California. One purpose of these is to inform farmers as to whether or not the soil water, which is being made available by the construction of drainage works and the pumping of water from wells, can be applied to the land continuously with-

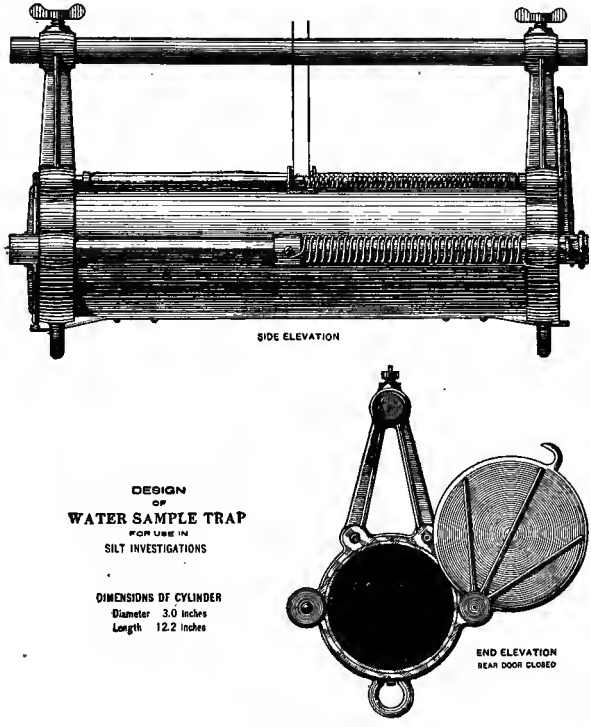


FIG. 5.—Water sample trap.

out danger of injury. Thus far the results of these analyses have been most encouraging, showing in nearly every case that the percentage of alkali is so small as to permit of the water being used with safety, and insuring a large increase in the irrigated area from this source of supply.

In collecting samples from the deep bayous of Louisiana and Texas, and from some of the streams where the percentage of silt is high, it has been desirable to ascertain whether there was any difference in the character of the water on the surface and at the bottom of the stream. The water sampler shown in figure 5 was devised for this purpose.[a]

[a] Two of these instruments are in the exhibit at St. Louis.

THE DRAINAGE INVESTIGATIONS.

The loss of water from leaky canals causes the temporary injury of many thousand acres of land in the irrigated districts of the West. This water finds its way through the subsoil in the fields below the canals from which it escapes, dissolving in its course the soluble salts in the soil through which it passes. In time it fills the subsoil in the lower lands, causing a gradual rise of the water plane until in places what were formerly productive fields become bogs and marshes, in which the roots of all vegetation are drowned out. As the soil water evaporates, it becomes more and more concentrated, until the water and soil become so strongly alkaline as to check the growth of plants, or prevent it entirely, leaving the ground bare of vegetation but covered with a crust of alkali. Seepage water, therefore, causes two injuries—it drowns out vegetation in some places by excess of water and kills vegetation in other instances by excess of alkali. It is estimated that in some of the older agricultural districts fully 10 per cent of the land once cultivated is now unproductive on account of the rise of seepage water.

Although much can be done to prevent seepage from canals, and to prevent waste and the escape of water from irrigated lands by economy in use, some loss is inevitable, and the overwatered area is gradually extending. Checking losses will not now restore the productiveness of the lands already injured. To relieve these lands of their surplus water and alkali, drainage is necessary. This necessity was recognized by Congress in making provision for the work of this Office for the year 1903, when a clause was inserted in the law providing for the study of "plans for the removal of seepage and surplus waters by drainage." For many years as fast as lowlands became unfit for cultivation they were abandoned, because it cost less to water new lands than to drain the old; but as longer canals are required to reach new lands, the expense becomes so great that better returns can be secured by the drainage of seeped lands. The exhaustion of the water supply helps on this tendency, since these lands when drained require much less water than higher lands, and the water drained from them can be used to irrigate other lands.

The most extended studies of drainage of irrigated lands have been carried on in California, Washington, and Utah. In the district about Fresno, Cal., where the water plane was once 70 feet below the surface, it has risen in places to 2 feet from the surface. Here the problem is to determine whether the water shall be carried off according to the plans of drainage in the humid sections or efforts made to intercept the water as it comes from canals. As a result of two seasons' field studies plans were made for two methods of drainage, one employing open ditches and the other draintiles. In the districts in Washington where injury was caused both from excess of water and alkali,

studies were made to determine the movements of the water in the soil and to ascertain the quantity of water which the drains must remove in order to keep the water level below a certain level. The reports of the investigations during 1903 show the results of these studies and furnish plans for the relief of the lands now being damaged.

The beginning of drainage studies in the arid region was followed by numerous requests for advice about the solution of drainage problems in the East. Much work has been done in Iowa, Wisconsin, and Illinois, and a beginning made in Louisiana and Florida. In Iowa there are two drainage problems of special importance. One is legislation which will enable the landowners of large districts to combine in carrying out comprehensive plans and the other is to have the plans in accord with the best drainage practice. The expert in charge of the drainage investigations has acted as an ex-officio member of a drainage commission to frame drainage laws in Iowa and has given advice about plans in numerous districts. Work of a similar character is being carried on in Illinois and Wisconsin.

The use of underdrains to prevent hillside erosion is also receiving attention. Experiments to determine the feasibility of this were carried on in northern Georgia. The cultivation of cotton on the uplands of the Southern States can only be insured by the adoption of engineering improvements which will protect hillsides from erosion. This crop requires clean culture and leaves no binding material in the soil to protect it during the winter storms. The farmers of that section have made extensive expenditures in the construction of ridges and terraces, but these have been only partially successful. In many places the water oozing through the soil on the ridges crops out at a lower point on the hillside, and these seepage spots start surface washing which in time forms deep gullies that necessitate the abandonment of the whole field. To prevent this tile have been laid in such a way as to intercept the seepage water and carry it off into protected surface channels. In the season which has elapsed since the experiment began one crop has been raised without any washing having occurred.

The demand for aid and advice regarding drainage has necessitated the extension of this portion of the investigation and led Congress at its last session to give it greater prominence in the work. In nearly every State in the Union there is a demand for preliminary surveys and the gathering of data necessary to the carrying out of drainage improvements in an effective manner. The question of the adaptability of different methods of drainage and the study of the legal and economic aspects of its problems is destined to form an important feature of this work for many years to come.

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LIST OF PUBLICATIONS OF THE OFFICE OF EXPERIMENT STATIONS ON IRRIGATION AND DRAINAGE—Continued.

Bul. 124. Report of Irrigation Investigations in Utah, under the direction of Elwood Mead, chief, assisted by R. P. Teele, A. P. Stover, A. F. Doremus, J. D. Stannard, Frank Adams, and G. L. Swendsen. Pp. 330. Price, $1.10.

Bul. 130. Egyptian Irrigation. By Clarence T. Johnston. Pp. 100. Price, 30 cents.

Bul. 131. Plans of Structures in use on Irrigation Canals in the United States, from drawings exhibited by the Office of Experiment Stations at Paris in 1900 and at Buffalo in 1901, prepared under the direction of Elwood Mead, chief. Pp. 51. Price, 60 cents.

*Bul. 133. Report of Irrigation Investigations for 1902, under the direction of Elwood Mead, chief. Pp. 266. Price, 25 cents.

Bul. 134. Storage of Water on Cache la Poudre and Big Thompson Rivers. By C. E. Tait. Pp. 100. Price, 10 cents.

Bul. 140. Acquirement of Water Rights in the Arkansas Valley, Colorado. By J. S. Greene. Pp. 83. Price, 5 cents.

Bul. 144. Irrigation in Northern Italy—Part I. By Elwood Mead. In press.

Bul. 145. Preparing Land for Irrigation and Methods of Applying Water. Prepared under the direction of Elwood Mead, chief. In press.

Bul. 146. Current Wheels: Their Use in Lifting Water for Irrigation. By Albert Eugene Wright. In press.

Bul. 147. Report on Drainage Investigations, 1903. By C. G. Elliott. Pp. 62. Price, 5 cents.

Bul. 148. Report of Irrigation Investigations in Humid Sections of the United States in 1903, under the direction of Elwood Mead, chief. In press.

FARMERS' BULLETINS.

Bul. 46. Irrigation in Humid Climates. By F. H. King. Pp. 27.

Bul. 116. Irrigation in Fruit Growing. By E. J. Wickson. Pp. 48.

Bul. 138. Irrigation in Field and Garden. By E. J. Wickson. Pp. 40.

Bul. 158. How to Build Small Irrigation Ditches. By C. T. Johnston and J. D. Stannard. Pp. 28.

Bul. 187. Drainage of Farm Lands. By C. G. Elliott. Pp. 40.